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EXHAUST GAS PURIFICATION SYSTEM OF AN INTERNAL COMBUSTION ENGINE AND METHOD FOR PURIFYING THE EXHAUST GASES THEREOF

The present invention relates to an exhaust gas purification system of an internal combustion engine having a device for selective catalytic reduction. The invention further relates to a method for purifying exhaust gases of an internal combustion engine, in which an exhaust gas stream is passed through a device for selective catalytic reduction.

Background Information

To lower the nitrogen oxide content of oxygen-rich exhaust gas, such as that emitted especially by diesel internal combustion engines and by internal combustion engines featuring direct gasoline injection, it is known to introduce a reducing agent into an exhaust tract. A suitable reducing agent is, for example, NH_3, which may be introduced as a gas into the exhaust gas stream. In that so-called selective catalytic reduction (SCR), the ammonia is selectively reacted with the nitrogen oxides present in the exhaust gas to form molecular nitrogen and water.

The insufficient activity of the known SCR system at exhaust gas temperatures below approximately 250° C is to be regarded as a problem. Upstream installation of an oxidation catalytic converter provides, on the one hand, for a lowering of the content of deactivating hydrocarbons and, on the other hand, for oxidation of NO to NO_2, which leads overall to a marked increase in NO_x conversion at exhaust gas temperatures above approximately 200° C. Especially when used in passenger automobiles, however, phases having such low exhaust gas temperatures occur relatively frequently, as is illustrated by a mean catalytic converter temperature of less than 180° C in

the known MVEG test cycle (MVEG: Motor Vehicles Emissions Expert Group; an expert group of the European Commission).

To ensure good distribution of the reducing agent over the SCR catalyst, a mixing section of approximately 40 cm, provided, where appropriate, with a mixing device, may be provided. A mixing device of that kind for an exhaust gas purification system is described in the earlier German Patent Application having the file reference 101 31 803.0. In that document, a mixing body disposed in the exhaust pipe has a gas impingement surface and a jet impingement surface, so that exhaust gas flowing out of the internal combustion engine may impinge upon the gas impingement surface, and reducing agent, which may be fed transversely to the exhaust gas stream, may impinge upon the jet impingement surface.

Summary of the Invention

An exhaust gas purification system configured in accordance with the present invention includes at least one oxidation catalytic converter disposed in an exhaust gas duct of an internal combustion engine and at least one device for selective catalytic reduction of the exhaust gases which is installed downstream of the oxidation catalytic converter. The exhaust gas purification system further includes a feed device for feeding reducing agent into the exhaust gas stream and admixing it therewith upstream of or in the device for selective catalytic reduction (SCR catalytic converter). According to the invention, the exhaust gas purification system has a switch-over device and/or a further feed device for selectively feeding reducing agent into the exhaust gas stream upstream of or inside the at least one oxidation catalytic converter. Using such a configuration of the

oxidation catalytic converter and so-called SCR catalytic converter it is possible to obtain a reduction in the NO_x emission limit values to below a quantity of emitted NO_x that ensures compliance with the permissible exhaust gas standards during the MVEG test cycle. Such a reduction in NO_x emissions may be achieved by additionally utilizing the temperature-resistant oxidation catalytic converter, which is already present and which is used for nitrogen oxide oxidation, for the purpose of NO_x reduction during a cold start phase. When installed close to the engine, the oxidation catalytic converter will already have reached a temperature of more than 100° C after about 50 seconds, which is sufficient for NO_x reduction using NH_3 or a reducing agent that splits off NH_3.

Oxidation catalytic converters mainly have noble metals such as platinum as the active component. Oxidation reactions of hydrocarbons, carbon monoxide and nitrogen monoxide are thereby promoted even at low temperatures. If NH_3 is injected as the reducing agent, these catalytic converters exhibit a relatively strong de-NO_x activity even at temperatures below 100° C.

If a configuration having a switch-over device instead of a separate feed device for the oxidation catalytic converter is chosen, this can reduce assembly costs. The present invention likewise includes, however, an embodiment having separate and separately controllable feed devices for reducing agent.

The switch-over device for selectively feeding the reducing agent into the exhaust gas stream upstream of or in the oxidation catalytic converter or into the SCR catalytic converter may be in the form of a valve, especially a 3/2-way

valve. In that manner, the reducing agent may be fed selectively to the oxidation catalytic converter or to the SCR catalytic converter, according to the temperature level that these have reached in driving operation.

One embodiment of the invention provides for the switch-over device to be in the form of a mixing valve. In that manner, it is possible for reducing agent to be admitted to the oxidation catalytic converter and the SCR catalytic converter simultaneously during a transition period. Using such a mixing valve, it is possible to avoid an abrupt switch-over, so that, depending upon the operating temperatures reached by the catalytic converters, an optimum purifying effect may be obtained.

The switch-over device is preferably temperature-controlled, so that, during a cold start phase with exhaust gas temperatures that are still low, reducing agent may be admitted to the oxidation catalytic converter and, after a warm-up phase, to the SCR catalytic converter.

The feed device preferably includes in each case a metering device for quantity metering and nozzles for distributing and atomizing the reducing agent in the exhaust gas stream.

Preferably, the at least one oxidation catalytic converter is disposed in the immediate vicinity of an exhaust gas outlet of the internal combustion engine, with the result that it reaches relatively high temperatures and thus achieves a high purifying effect after only a short time.

As the reducing agent, there comes into consideration, for example, an ammonia-containing or ammonia-releasing substance

capable of effecting NO_x reduction. Examples of such a substance that come into consideration are urea and ammonium carbamate.

In a method according to the present invention for purifying exhaust gases of an internal combustion engine, in which method an exhaust gas stream is passed through at least one oxidation catalytic converter disposed in the exhaust gas duct and through at least one device for selective catalytic reduction (SCR catalytic converter) installed downstream of the oxidation catalytic converter, there is fed to the exhaust gas stream a reducing agent which, according to the present invention, is selectively fed to the exhaust gas stream upstream of or inside the at least one oxidation catalytic converter. The reducing agent is selectively fed to both catalytic converters simultaneously or to only one of the catalytic converters. The reducing agent is distributed and atomized preferably by a nozzle.

One embodiment of the method according to the present invention provides for temperature-controlled feeding of the reducing agent into the oxidation catalytic converter and/or into the device for selective catalytic reduction.

If NH_3 is admitted to the oxidation catalytic converter, the latter exhibits a relatively pronounced de-NO_x activity at temperatures below 100° C. The useful temperature window for NO_x reduction is relatively narrow, however, since above approximately from 250° C to 300° C nitrogen reduction no longer takes place but, rather, additional nitrogen oxide production takes place as a result of oxidation of NH_3. In addition, relatively high N_2O selectivities may possibly be observed. It must, therefore, be ensured that reducing agent

is admitted to the oxidation catalytic converter only in a starting phase (in the MVEG test, only up to about 350 s). Preferably, the reducing agent is fed into the oxidation catalytic converter at exhaust gas temperatures of less than approximately from 150° C to 200° C in the oxidation catalytic converter.

After such a period of time, the SCR catalytic converter will normally also have reached its operating temperature and injection of reducing agent is switched to the SCR catalytic converter. That may be done at temperatures of approximately from 150° C to 200° C in the SCR catalytic converter. Metering of reducing agent onto the oxidation catalyst is possible in principle at operating points with a low exhaust gas temperature - that is to say, not only in the case of cold starting - and promises a very effective NO_x-lowering potential in cases where only insufficient activity is achieved with the SCR catalytic converter. With injection upstream of the oxidation catalytic converter up to a time of about 600 s, therefore, a marked increase in conversion by the exhaust gas purification system is to be achieved. A suitable, sensible switch-over point of the temperature-controlled switch-over valve may lie at from 100 to 200° C, preferably at from 130 to 180° C.

A practical embodiment of the system may, for example, provide a 3/2-way switch-over valve which is operated in dependence upon the catalytic converter temperatures and the operating point of the engine. Equipping an existing system in that manner is relatively simple and can be done with only little expenditure. The catalyst system, the temperature sensors and the metering system are already present and nor is it

necessary for those components to be modified. Only the switch-over valve and the reducing agent feed line upstream of the oxidation catalytic converter have to be retrofitted. By a suitable metering strategy, it is possible for effective reduction of the nitrogen oxides to be achieved over an entire test cycle (MVEG cycle). In the MVEG test, it is possible for an increase in NO_x conversion of approximately 40% to be achieved, with the result that in the case of lowered untreated emissions it is even possible to meet the relatively strict U.S. standards.

The oxidation catalytic converter may, in a preferred embodiment, be in the form of a catalytically coated particle filter. The catalytic coating of the particle filter acts in this case similarly to the coating of a known oxidation catalytic converter. It is furthermore possible for a separate particle filter, which effects filtering of the soot particles, to be provided between the oxidation catalytic converter and the SCR catalytic converter.

The present invention is described in detail below in preferred exemplary embodiments with reference to the associated drawings, in which:

Figure 1 is a diagrammatic illustration of an internal combustion engine having an exhaust gas after-treatment unit in an exhaust gas duct,

Figure 2 is a diagrammatic illustration of the internal combustion engine according to Figure 1 in a first operating position,

Figure 3 shows the internal combustion engine according to Figure 1 in a second operating position,

Figure 4 shows typical temperature variations of the components of the exhaust gas purification system during a test cycle,

Figure 5 shows typical NO_x emission values during a test cycle, and

Figure 6 is a qualitative diagram illustrating the SCR activity of an oxidation catalytic converter.

Figure 1 shows an exhaust gas purification system according to the present invention in diagrammatic form. In that diagram, an oxidation catalytic converter 4 and a device for selective catalytic reduction, referred to as SCR catalytic converter 6, are disposed in an exhaust gas duct 28 of an internal combustion engine 2. Internal combustion engine 2 has an intake duct 21 for supplying fresh mixture 22, and outlet ducts 26 which are combined in a manifold 27 to form exhaust gas duct 28. Disposed in the exhaust gas duct is an exhaust gas turbine 24 of an exhaust gas turbocharger 23, which turbine 24 is coupled via a shaft 25 to a compressor, not shown here. Exhaust gas turbocharger 23 is optional and serves to improve the performance and exhaust gas emission characteristics of internal combustion engine 2.

Internal combustion engine 2 is preferably a diesel internal combustion engine featuring auto-ignition or a gasoline engine featuring direct fuel injection. Both types of engine emit a relatively oxygen-rich exhaust gas. Exhaust gas stream 29 passes successively through oxidation catalytic converter 4 and SCR catalytic converter 6 and leaves the exhaust gas

purification system as purified exhaust gas 14 which is passed into the open air via a muffler (not shown).
The exhaust gas purification system further includes a feed device 8 for feeding a reducing agent 81 into exhaust gas stream 29. Feed device 8 includes a switch-over device 83 and also a first connection line 84, which is connected to a first nozzle 85, and a second connection line 86, which is connected to a second nozzle 87. First nozzle 85 is disposed upstream of oxidation catalytic converter 4 in exhaust gas duct 28 and serves to finely distribute and atomize reducing agent 81 upstream of oxidation catalytic converter 4. Second nozzle 87 is disposed upstream of SCR catalytic converter 6 and downstream of oxidation catalytic converter 4 and serves to feed reducing agent 81 into exhaust gas stream 29 upstream of SCR catalytic converter 6.

First and second connection lines 84, 86 open into switch-over device 83 which is able to provide for selective distribution of the reducing agent to first and/or second connection line 84, 86. Switch-over device 83 is controlled preferably temperature-dependently, so that, in a cold running phase, reducing agent 81 may be admitted to oxidation catalytic converter 4 and, after a certain temperature has been reached, to SCR catalytic converter 6.

Figure 2 illustrates the cold running phase of the exhaust gas purification system, in which reducing agent is admitted only to first nozzle 85. This is illustrated by arrow 81 along first connection line 84.

Figure 3 illustrates the subsequent phase, in which the catalytic converters have already reached a predetermined operating temperature. In this case, reducing agent 81 is

admitted to second connection line 86 and second nozzle 87. This is illustrated by arrow 81 along second connection line 86.

A typical transition temperature may lie at approximately from 100° C to 200° C, preferably at about from 130 to 180° C, above which a switch-over to admission of reducing agent 81 to SCR catalytic converter 6 may take place. A switch-over may also be made in an advantageous manner by a mixing valve, which is able to provide for simultaneous admission to oxidation catalytic converter 4 and SCR catalytic converter 6 in the transition temperature range.

Also included within the present invention is an alternative configuration that provides two separate feed devices for the oxidation catalytic converter and the SCR catalytic converter.

In an alternative embodiment, oxidation catalytic converter 4 may be a catalytically coated particle filter which, by virtue of its catalytic coating, has the same effect as a known oxidation catalytic converter. In addition to the configuration shown, a separate particle filter may be disposed between oxidation catalytic converter 4 and SCR catalytic converter 6. That particle filter produces a further improvement in the purifying effect on the exhaust gases.

Figure 4 illustrates typical temperature variations of the oxidation catalytic converter and the SCR catalytic converter during a standardized test cycle. The so-called MVEG test will be referred to hereinafter as an example of a test cycle. The time in seconds is plotted on the horizontal axis and the temperature in ° C on the vertical axis. It will be apparent that the oxidation catalytic converter (upper, jagged curve)

is capable of reaching temperatures of up to 200° C after a period of as little as approximately 150 seconds. The temperature of the SCR catalytic converter (lower, undulating curve) is still distinctly below 150° C after 300 seconds. At those temperature ranges in the SCR catalytic converter, feeding of reducing agent will not yet produce satisfactory reduction results for NO_x. Since the oxidation catalytic converter reaches temperatures of more than 100° C after only a few seconds, it is possible for good NO_x reduction to be already achieved by feeding reducing agent upstream of or into the oxidation catalytic converter. The dashed vertical line at approximately 300 seconds represents the earliest sensible time to commence NH_3 injection upstream of the SCR catalytic converter. The continuous vertical line at approximately 350 seconds represents the start of effective NO_x reduction by the SCR catalytic converter in the MVEG test cycle.

Figure 5 illustrates the cumulative emission of NO_x over time in various systems for exhaust gas purification. The time in seconds is shown on the horizontal axis and the cumulative amount of emitted NO_x is shown on the vertical axis. It will be apparent that, by injecting reducing agent upstream of the oxidation catalytic converter and in the SCR catalytic converter in accordance with the present invention, it is possible for emissions of NO_x to be markedly reduced.

Lowermost curve 20 illustrates that only with the system according to the present invention is it possible to comply with the MVEG limit value of 0.9 g of NO_x. Discontinuous curve 22 extending above the latter characterizes the curve for NO_x emissions in a conventional system composed of oxidation catalytic converter and SCR catalytic converter arranged in

series (so-called conventional VR system without switch-over). Curve 24 illustrates the emissions of a system that provides feeding of reducing agent merely upstream of the oxidation catalytic converter. At first, good reduction takes place, whereas the elevated temperatures at and beyond approximately 800 seconds prevent effective NO_x reduction. From that point in time, the NO_x emissions rise steeply and even approach the values of untreated emissions (curve 26), since, at and above approximately from 300 to 350° C, an additional quantity of NO_x is produced.

Figure 6 illustrates the NO_x-reducing effect of the oxidation catalytic converter over temperature. It will be apparent that, at and above a temperature of approximately 200° C, NO_x reduction falls markedly and that, at and above temperatures of approximately 350° C, NO_x is even additionally produced. The temperature is shown on the horizontal axis and the conversion is shown on the vertical axis. It will be apparent that the conversion of NO_x declines markedly at and above a certain temperature (approximately 200° C). That is the reason why, after the cold running phase, the feeding of reducing agent upstream of the oxidation catalytic converter must be discontinued and reducing agent may continue to be fed only upstream of the SCR catalytic converter.